
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
U. S. Weather Bureau

Southern Region Technical Memorandum No. 28, September 1966

THE WEATHER DISTRIBUTION WITH UPPER TROPOSPHERIC COLD LOWS IN THE TROPICS

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1. Introduction

Upper tropospheric cold lows are one of the most puzzling of all tropical weather systems. They occur primarily during the summer months, forming and remaining south of the subtropical ridge axis. They are to be distinguished from the winter "kona" storms which have their origin in the westerlies; although, in some cases the summer lows can be traced back to cutoff pools of cold air in extended westerly troughs. However, in general, they form in the tropics and remain there during most of their life. Palmer (1951) made the first reference to these perturbations, documenting two cases in the Pacific. Riehl (1954), also did pioneering work within this area.

The high-level cyclone attains maximum intensity near 200 mb, Ricks (1959), and may extend vertically downward either as a closed vortex or as a wave perturbation to the surface; although, more commonly they remain above the 10,000 ft. level. Their lifetime varies considerably. Some have been tracked in nearly quasi-steady state for periods longer than a week. Others can be traced for only a few map times. The associated weather is not always the same. Sometimes there is extensive cloudiness and precipitation. Other times skies are nearly clear. This suggests a reversal in the vertical circulation. In either case it is difficult to justify the energetics of the system. When descent takes place, with associated conversion of potential to kinetic energy, how is the cold core maintained? On the other hand, with extensive ascent and accompanying release of latent heat what prevents the air from being heated? In the latter case, one might also inquire about the energy source since the circulation is indirect.

From the viewpoint of an operational forecaster, the weather distribution poses the greatest problem. What are the conditions which determine whether the low will be "wet" or "dry"? This study is an attempt to shed light on this problem.

II. Summer of 1958

The initial phase of this study was aimed at organizing the weather associated with the upper lows into meaningful patterns. Attention was confined to the summer of 1958. There were several reasons for selecting this year. First, a good selection of weather charts were available. On file in the office of the National Hurricane Center were maps for approximately every 10,000 ft.; i.e., surface, 700 mb, 500 mb, 300 mb and 200 mb. In addition, the National Hurricane Research Project at this time was preparing a weather depiction chart on which ship reports were composited for the 18 hour period from 7 AM to 7 PM. Included on this map are the 1800Z land reports. Second and more important, the radiosonde network in the Caribbean was at its best in 1957 and 1958. Since then, the Cuban crises and a de-emphasis of the Atlantic missile range stations has resulted in a gradual deterioration of reporting stations. In 1958 there were 20 radiosonde stations in the Caribbean. Today, there remain only 17 of which two take only one sounding a day. This represents nearly a 25% reduction!

The first step was to establish cold low tracks for each month from June through October. The analysis was confined to the area of the Caribbean and Bahama Islands where the data was sufficient to insure fairly accurate positions. It has been known for some time that in the tropics systems in the upper and lower troposphere often move independent of each other. In order to isolate the weather caused by the upper cyclones, it was necessary to restrict the study to lows which were not contaminated by systems at other levels. Therefore, perturbations in the middle and lower troposphere, such as easterly waves, were also followed. Only these lows in which lower systems were removed by at least 10 degrees latitude were considered. This limited the study to 78 cold low days. A "cold low day" is defined as a day in which an uncontaminated low appeared on the map. If two such lows occurred on any given day, it would be counted as two "cold low days".

Next the vertical extent of the low was determined. This is the lowest level at which either a vortex or a trough could be detected.

The weather depiction charts were used to obtain the associated weather in the following manner. The 1800Z cyclone positions were entered on these charts and a circle of 5 degrees latitude radius drawn. The percent of this circle covered by cloud cover greater than 50% (broken or overcast conditions) was estimated. Also, the percent of the land stations and ships within the circle reporting precipitation were determined. Here, precipitation is defined as any reference to rain in either present or past weather.

Table 1 summarizes the results. The left side of the table shows the relationship between cloudiness and the vertical depth of the low. The percent of the circle covered by cloudiness greater than 50% was divided into the three divisions shown. Recorded in the table are the number of "cold low days" which fall into the various categories. On the right side, the relationship between the vertical extent and precipitation is revealed. The following points can be noted.

A. The majority of the lows are confined to the upper troposphere. Over 60% do not penetrate as low as 700 mb and only around 10% are reflected as low as the surface.

B. There is a direct relationship between vertical extent and weather. None of the lows confined to the upper troposphere (bases above 500 mb) were associated with significant cloudiness. On the other hand, all which extended downward to the surface displayed considerable cloudiness. The same conclusion is verified on the right side of Table 1, where it is observed that the percentage of either ships or stations reporting precipitation almost doubles for lows extending to the surface as compared to cyclones confined to the extreme upper troposphere. It should also be noted that even in the "wet" case, precipitation is not extensive over a large area. On an average less than 25% of the ships reported rain.

III. Case Studies

These results are verified nicely by three case studies involving Tiros data.

Case 1. "Wet" low

Frank (1963) discussed the origin of an unnamed tropical storm in September 1961. This storm developed from an upper level cold low. Tiros pictures on September 9 and 10 illustrate the weather distribution associated with a "wet" low.

Although limited data does not permit a precise determination of the base of the low on the 9th, it undoubtedly extended downward into the lower troposphere. Twenty-four hours later, on the evening surface map of the 10th (0000Z, September 11), a weak pressure trough was evident, figure 1. Figures 2 through 5 show the Tiros mosaics and 200 mb streamline charts for these 2 days. Included on the 200 mb maps are the nephanalysis made from the mosaics. Ship reports indicate the cloudiness on both days was mainly middle and high types with very few reports of precipitation. The percent of a 5 degree latitude circle, centered on the cyclone, covered with cloudiness varies from around 60% on the 9th to nearly 90% on the 10th. This increase in cloud cover is consistent with the marked intensification which was taking place.

The mosaics, figures 2 and 4, show that the cloudiness tends to be concentrated on the periphery of the vortex and is not symmetrical. The heavier cloudiness is located in the eastern semicircle. The inner 200 miles are relatively cloud free. This suggests that the cold air near the center is descending and the sense of the circulation is direct; i.e. potential energy is being converted to the kinetic energy of motion.

Case 2. "Wet" low

Figure 6 shows the track of another "wet" low which formed southwest of Bermuda on September 12, 1965. This system tracked westsouthwestward until the 15th then recurved into the westerlies.

Three aircraft from the Research Flight Facility under the support of the National Hurricane Research Laboratory investigated this low on September 14, 15, and 16. The altitudes of the planes were 850 mb, 500 mb and 250 mb. On all three days the low extended to the surface where a sharp trough was evident in the pressure pattern.

Figures 7 through 9 show a schematic picture of the cloudiness and radar echoes observed aboard the aircraft on each day. Superimposed are the 200 mb winds and streamlines. The outer limit of the cloud observations is indicated by a sawtooth line. The planes at the lower and middle level flew the track shown in the figures. The high level aircraft followed a slightly different path because of fuel limitations.

Tiros pictures were available on the 13th and 16th, figures 10 and 11. Unfortunately, mechanical difficulties prevented photos on the 14th and 15th.

The aircraft observations as well as Tiros pictures confirm the results found in case 1. The cloud distribution is asymmetrical being primarily concentrated in the eastern semicircle. Departing the low center towards the east, a very thin cirrus shield was observed which gradually thickened and lowered. Around 200 miles from the center an altostratus deck was encountered. Nearly 300 miles away an extensive area of convection was observed on radar.

Over the western quadrant pronounced subsidence was evident with widely scattered flat cumulus. Twice the low level aircraft climbed into a weak subsidence inversion located just above the 850 mb level.

It is interesting to see that the well marked spiral character of the cloud structure observed in figures 2 and 4 is not as prevalent in figures 10 and 11.

Case 3. "Dry" low

The final example is a "dry" low which moved into the central Bahama Islands on the 25th and continued slowly westward through the Florida straits on the 26th and 27th. Figures 12 through 14 show the structure of this cyclone at three levels; 700 mb, 250 mb and 100 mb. The data on these diagrams represent a 48 hour composite (5 map times) centered on 1200Z, July 27, 1964. The 200 mb low position is indicated on both figures 12 and 14.

The vortex is well defined at 250 mb with a maximum wind of 45 knots. There is no evidence of the circulation at 100 mb, and the 700 mb level is very near the base of the cyclone.

Figures 15 and 16 are Tiros pictures of this low on the 25th and 27th. The circulation center on the 25th is in the lower left hand corner of figure 15 near latitude 23 degrees north and longitude 73 degrees west. On this day cloudiness is at a minimum.

Two days later, figure 16, a small overcast area appears in the west and southeast quadrants of the vortex. The rather extensive cloudiness along the left edge of this figure is related to a lower tropospheric trough over extreme northern Florida and not to the upper low. Apart from this, the total overcast area within a 300 mile circle would be around 25%. Cloudiness associated with land masses in this picture makes it difficult to separate the two influences.

IV. Conclusions

A. Most cold lows are confined to the upper troposphere. Cyclones which extend downward into the lower troposphere are not nearly as common.

B. The weather associated with a cold low is directly related to the level of its base in the vertical. Significant amounts of cloudiness and precipitation do not occur until the vertical circulation extends downward far enough to tap moisture in the lower troposphere. This means "dry" lows are far more common.

C. Even in the case of a "wet" low, precipitation is not widespread. As a matter of fact a previous study by Frank (1963) indicates that when the convective activity becomes extensive, the cyclone warms and is destroyed.

D. Cloudiness around the cyclone is asymmetric. In the examples shown, the heavier overcast areas were to the east. However, other cases have been found where the main cloud cover was in the western semicircle. This appears to be related to the speed of propagation versus the strength of the basic current in the layer which is feeding the vortex.

E. A cloud minimum exists in the immediate vicinity of the center where temperatures are coldest. This suggests subsidence and would permit a direct circulation.

Table 1. Summary of the weather associated with upper tropospheric cold lows within a 5 degree latitude radius circle centered on the low. The number of cold lows which fall into each catagory are listed on the left side. On the right, the average number of either ship or land reports with precipitation is recorded.

Base of low	% of circle covered by broken or overcast cloudiness				Average % of reports with precip.	
	<35%	35-65%	>65%	Total	land stations	ships
300 mb	20	0	0	20	33	12
500 mb	17	9	2	28	43	16
700 mb	14	5	3	22	37	10
surface	0	4	4	8	58	22
Total	51	18	9	78		

Acknowledgements

The author is deeply indebted to Dr. Cecil Gentry of the National Hurricane Research Laboratory for all the assistance provided. The multi-level investigation flights were made possible through the support of NHRL. The author would like to also thank Mr. Lester Hubert of National Weather Satellite Center for furnishing the Tiros Picture used in this paper.

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Palmer, C. E., 1951: On high level cyclones originating in the tropics. Trans. Amer. Geophys. Union, 32, 683-696.

Ricks, E. L., 1959: On the structure and maintenance of high tropospheric cold-core cyclones of the tropics. Unpublished master's thesis, University of Chicago, pp 31.

Riehl, H., 1954: Tropical Meteorology. McGraw-Hill Book Company, Inc. New York, pp 381.

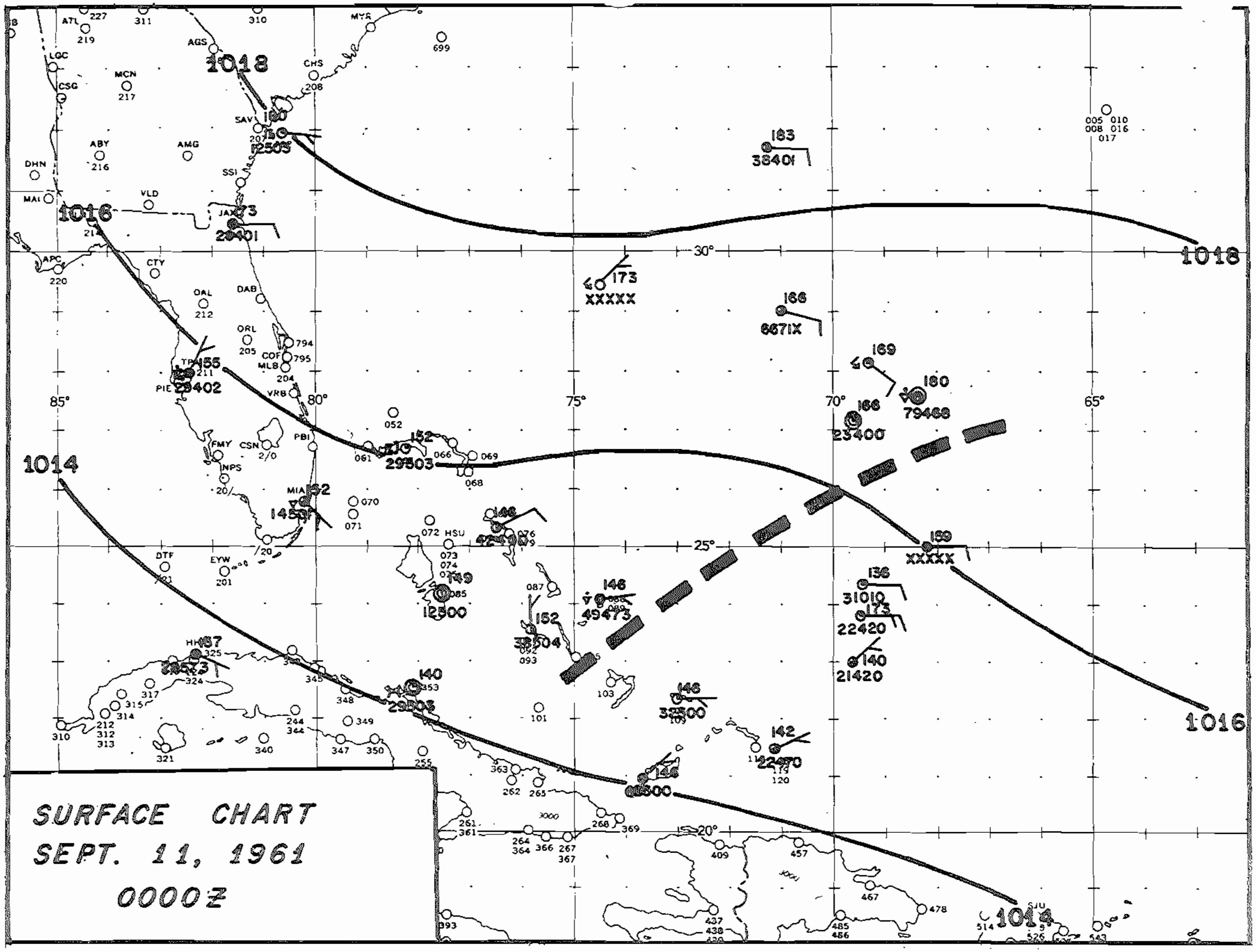

Figure 1. Surface map 00Z, September 11, 1961 showing the downward reflection of an upper cold Low in the pressure pattern

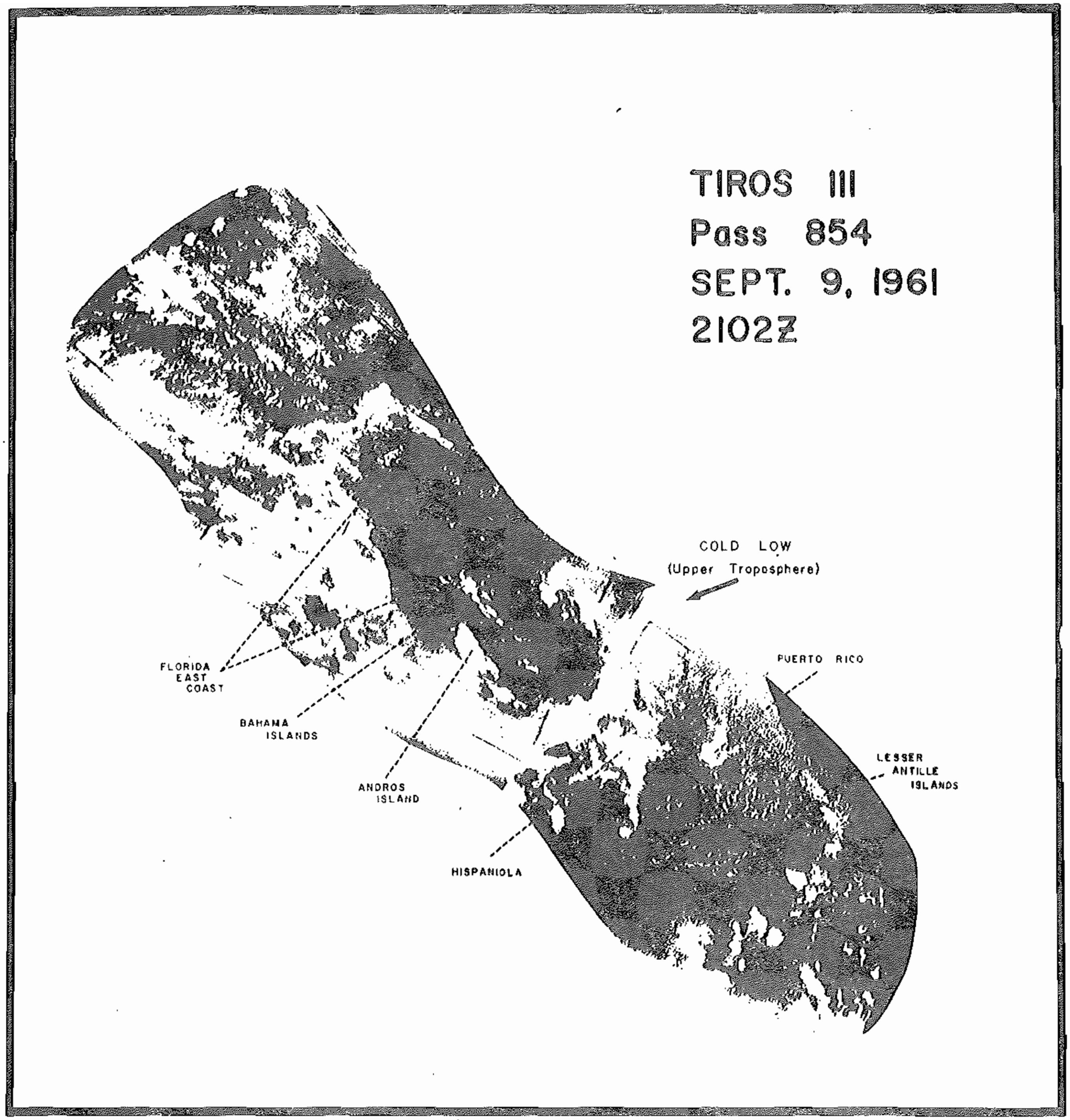

Figure 2. Tiros mosaic on September 9, 1961 showing the cloud distribution with a "wet" cold low. See the nephanalysis on figure 3 to locate the low center.

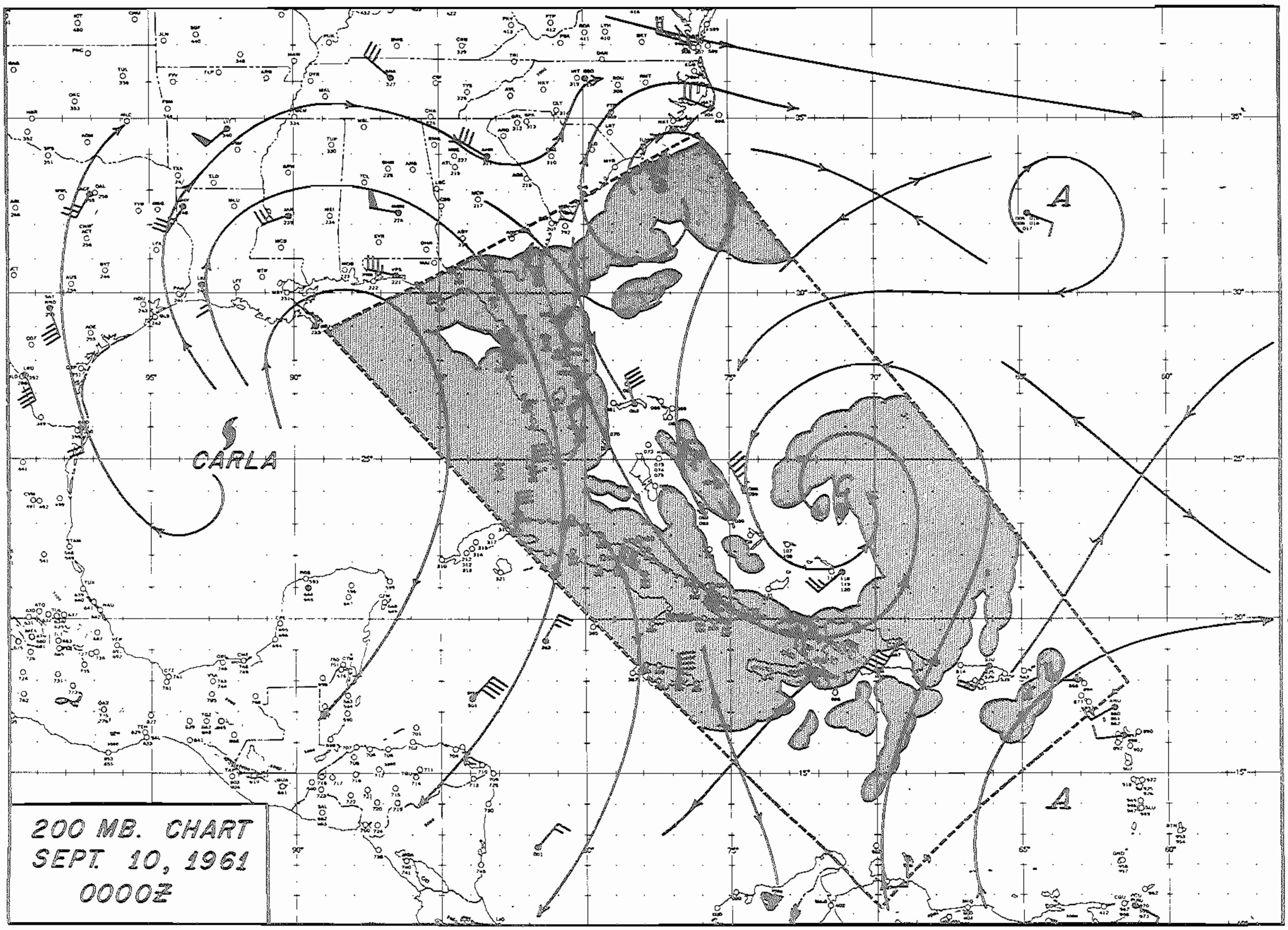

Figure 3. 200 mb Streamline chart for 00Z, September 10, 1961 showing a "wet" cold low. The nephanalysis was made from Figure 2.

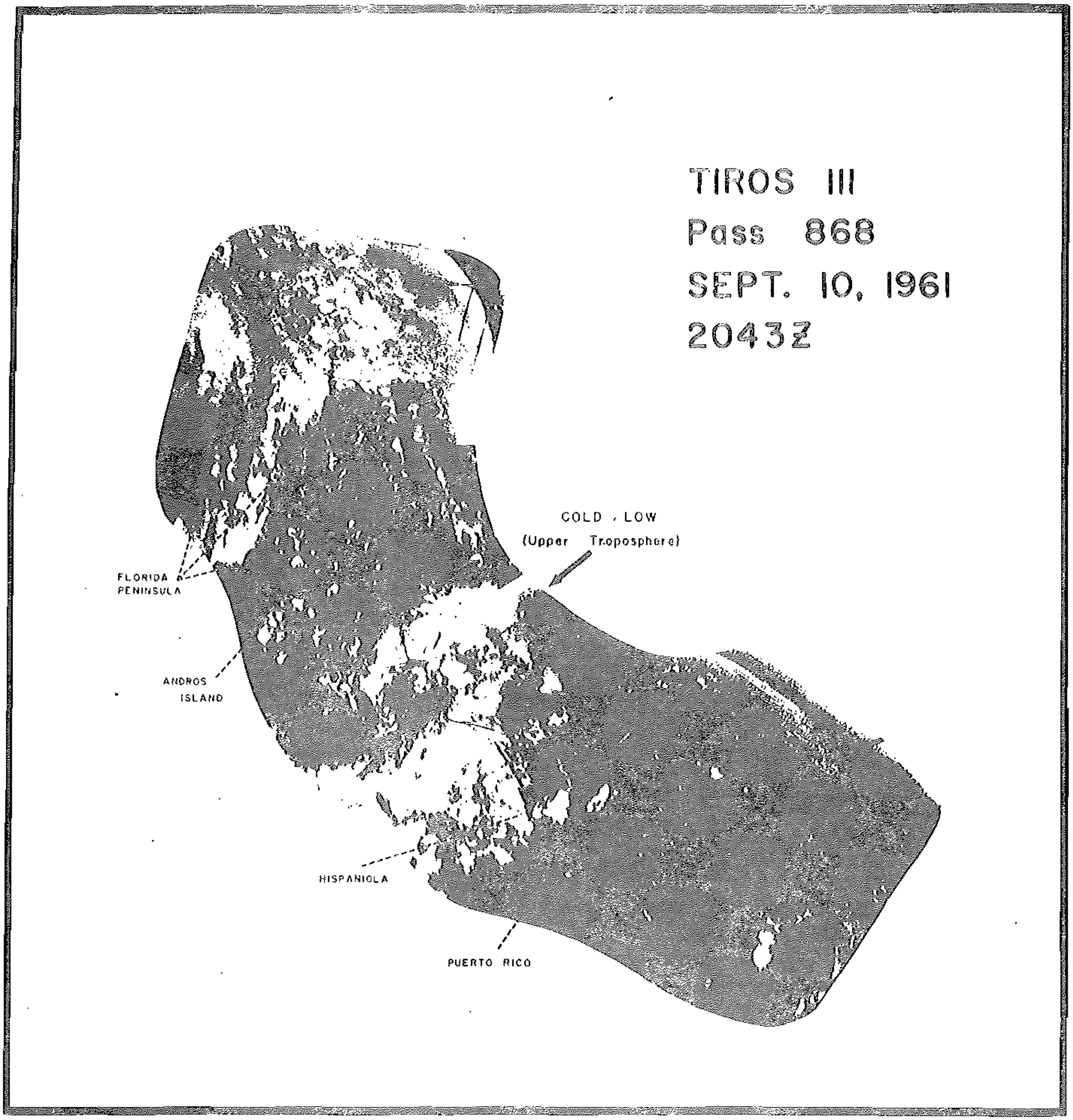

Figure 4. Tiros mosaic on September 10, 1961 showing the "wet" low of figure 2 on the following day. See the nephanalysis on figure 5 to locate the low center.

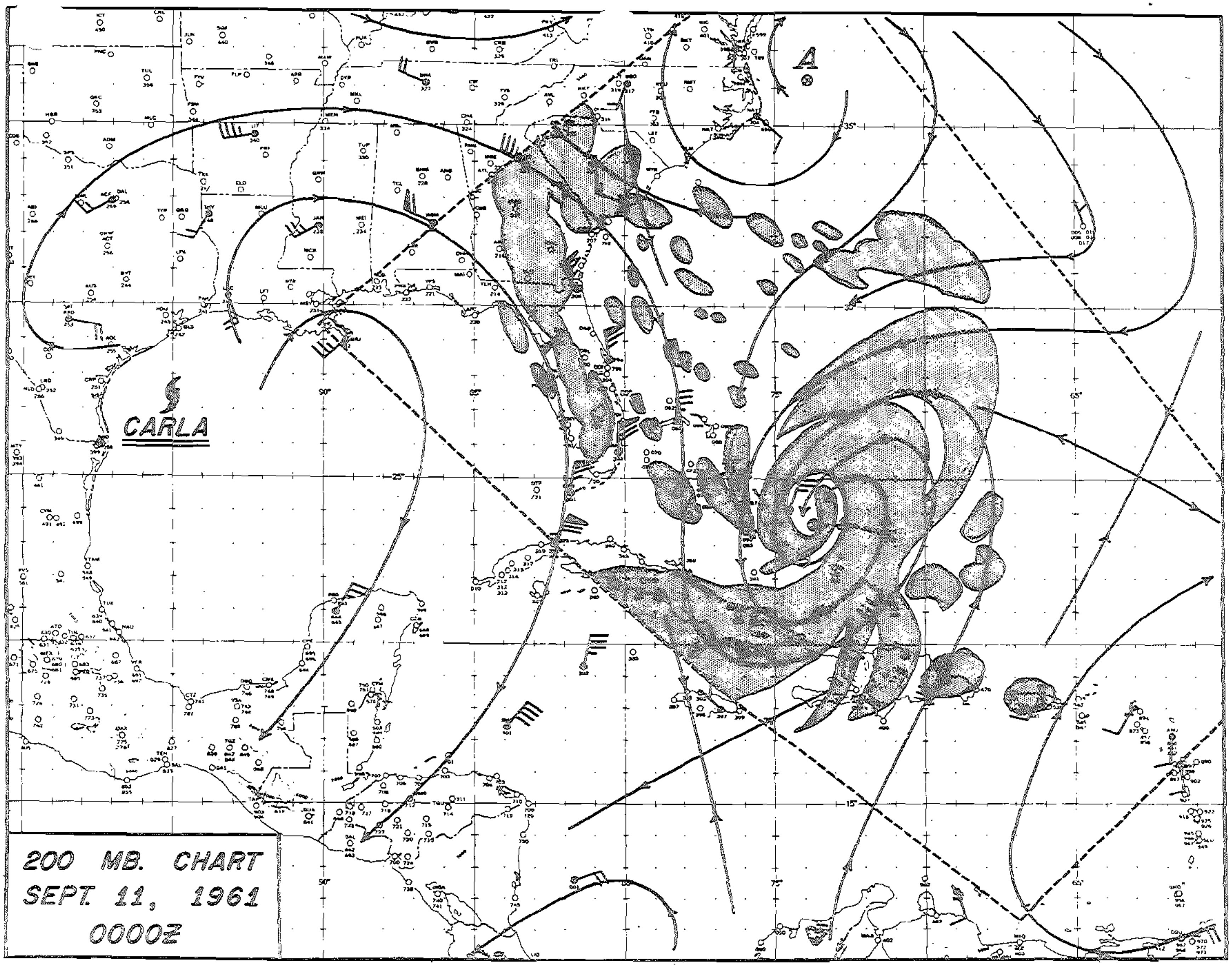

Figure 5. 200 mb Streamline chart for 00Z, September 11, 1961 showing the "wet" low of figure 3 on the following day. The nephanalysis was made from figure 4.

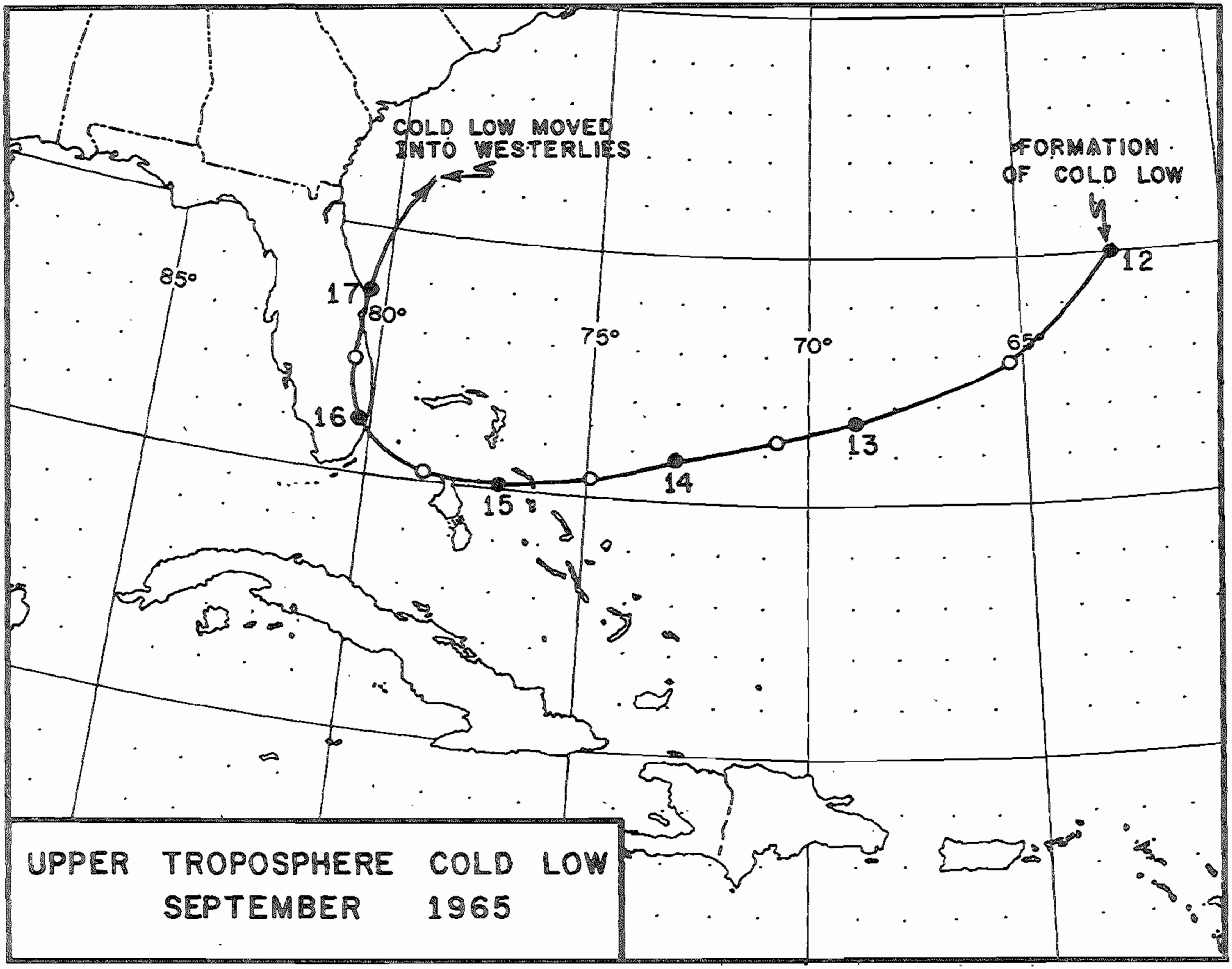

Figure 6. Track of a "wet" low ι was investigated by three Research Flight Facility aircra_ ɔn September 14, 15, and 16.

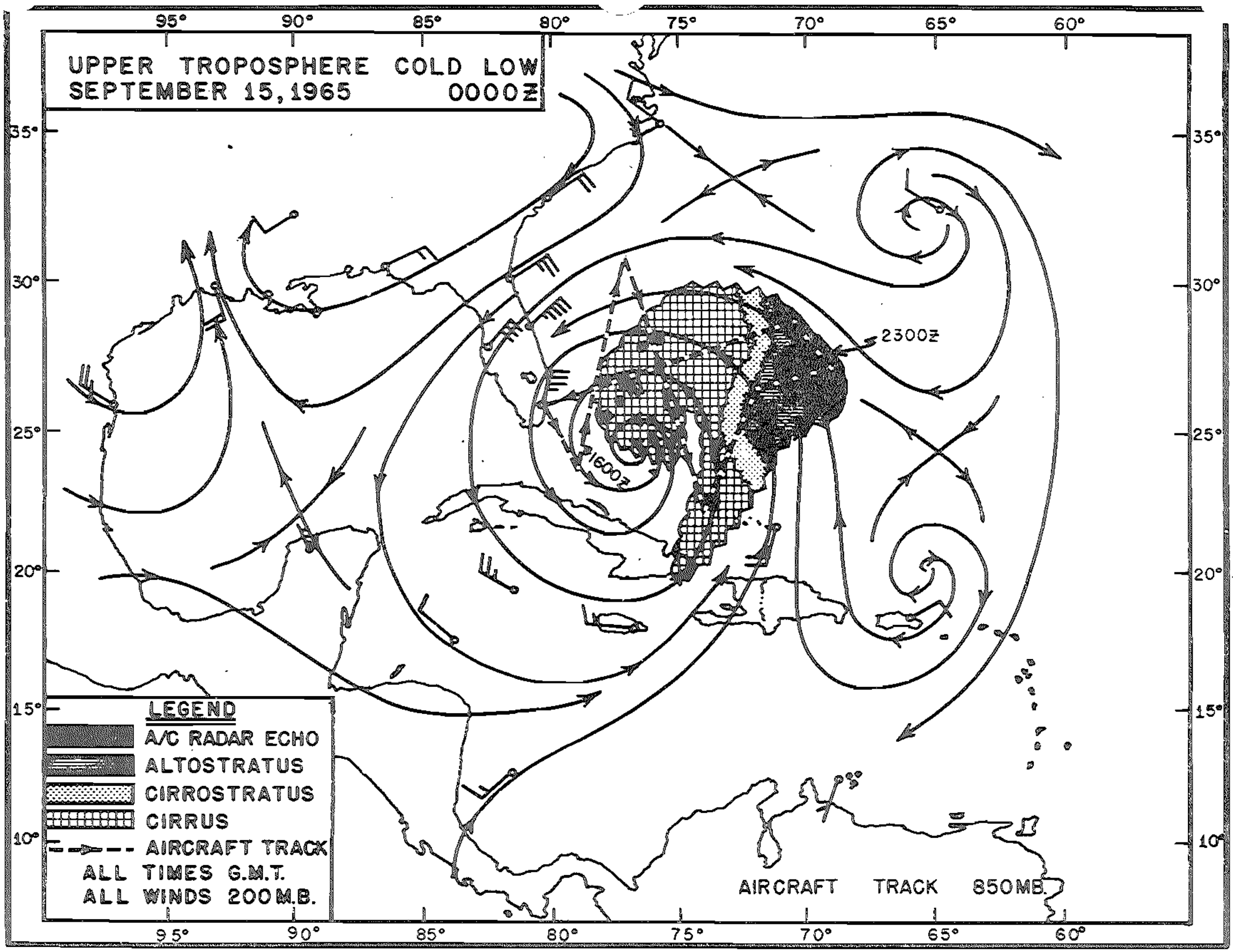

Figure 7. 200 mb Streamline chart for 00Z, September 15, 1965 showing a "wet" cold low. Superimposed is the weather distribution as observed on board the aircraft. The sawtooth line indicates the outer limit of the observation

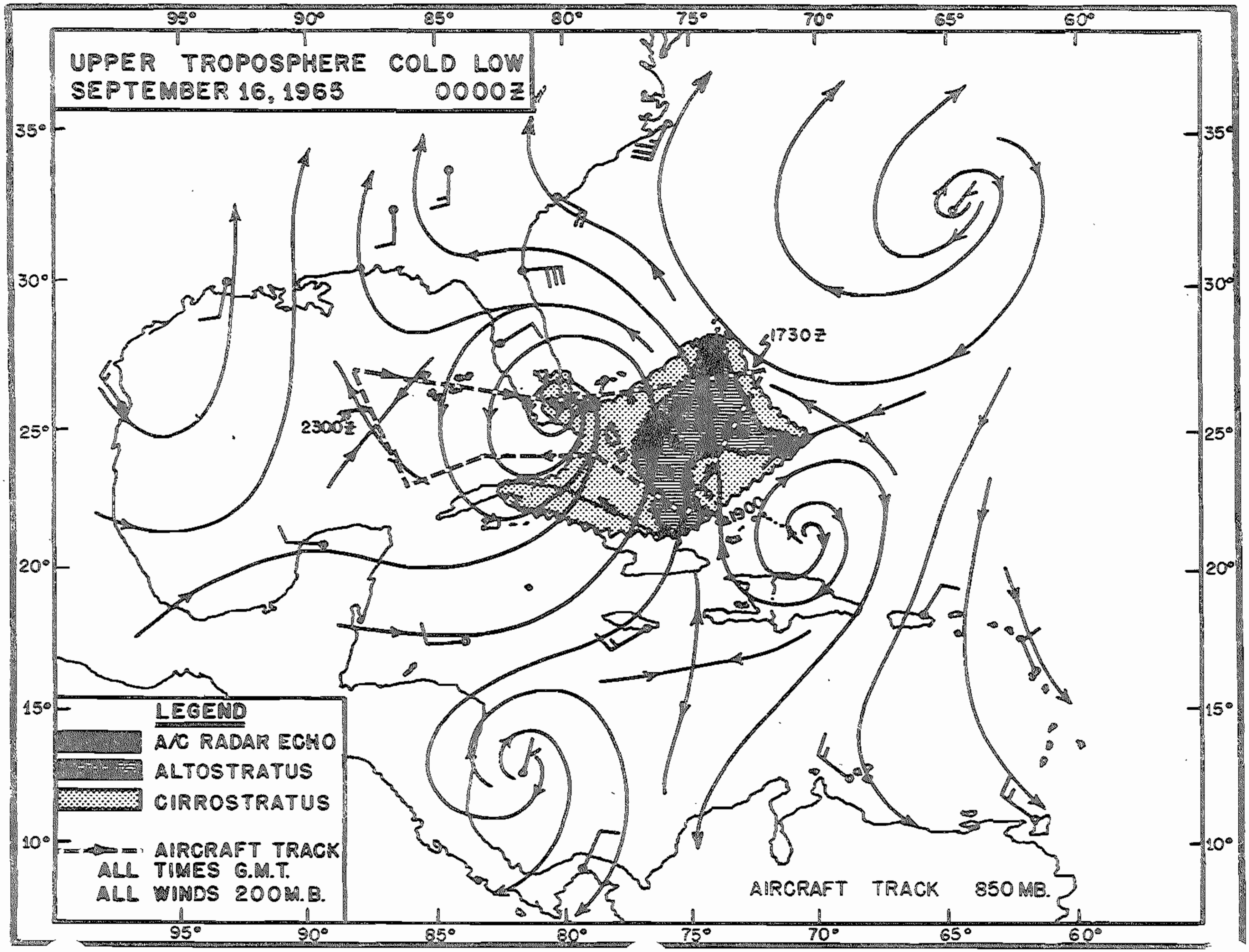

Figure 8. Same low as shown [illegible] gure 7 on September 15, 1965.

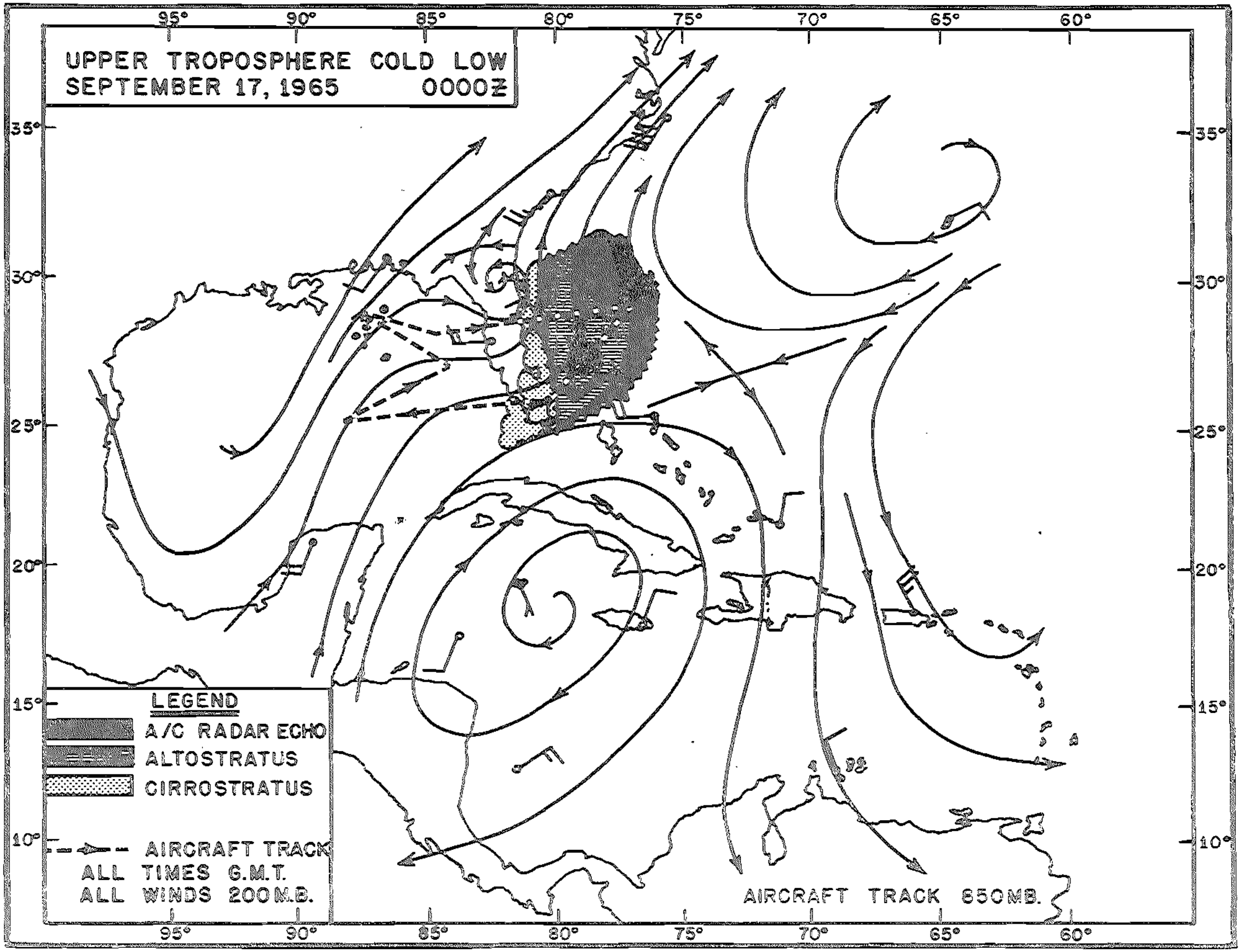

Figure 9. Same low as in figures 7 and 8 on September 16, 1965.

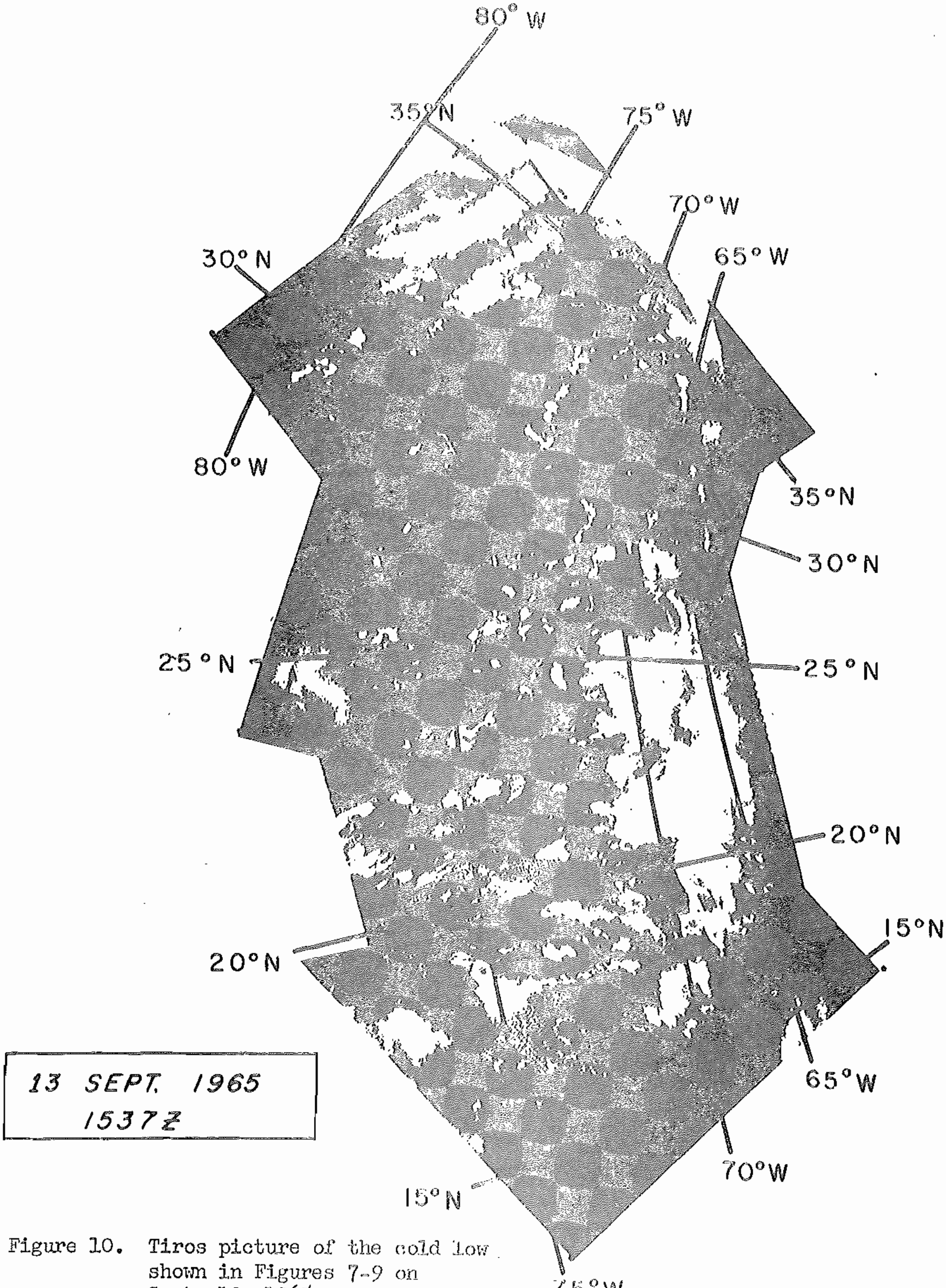

Figure 10. Tiros picture of the cold low shown in Figures 7-9 on Sept. 13, 1965

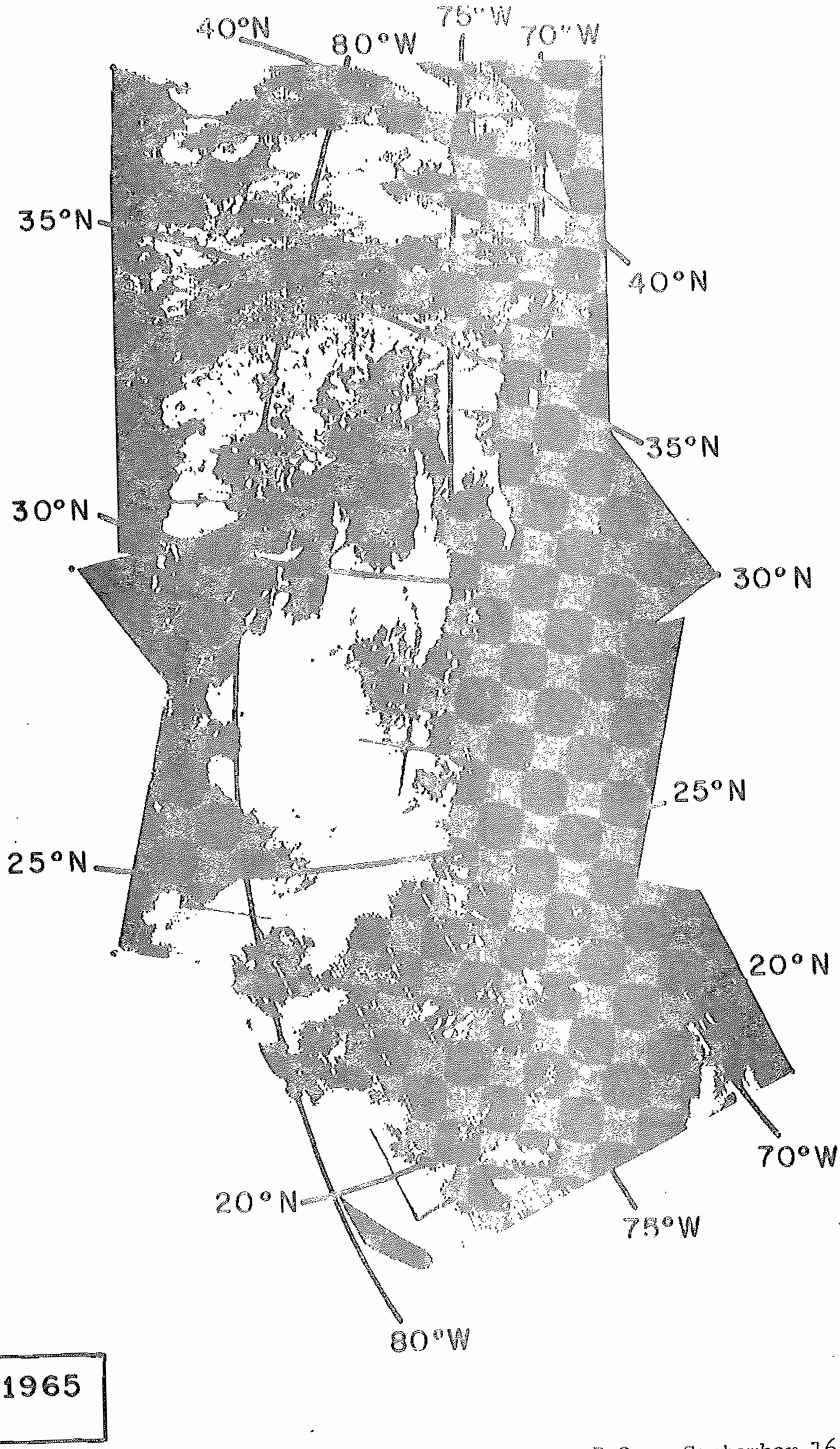

Figure 11. Tiros picture of the cold low shown in figures 7-9 on September 16,1965.

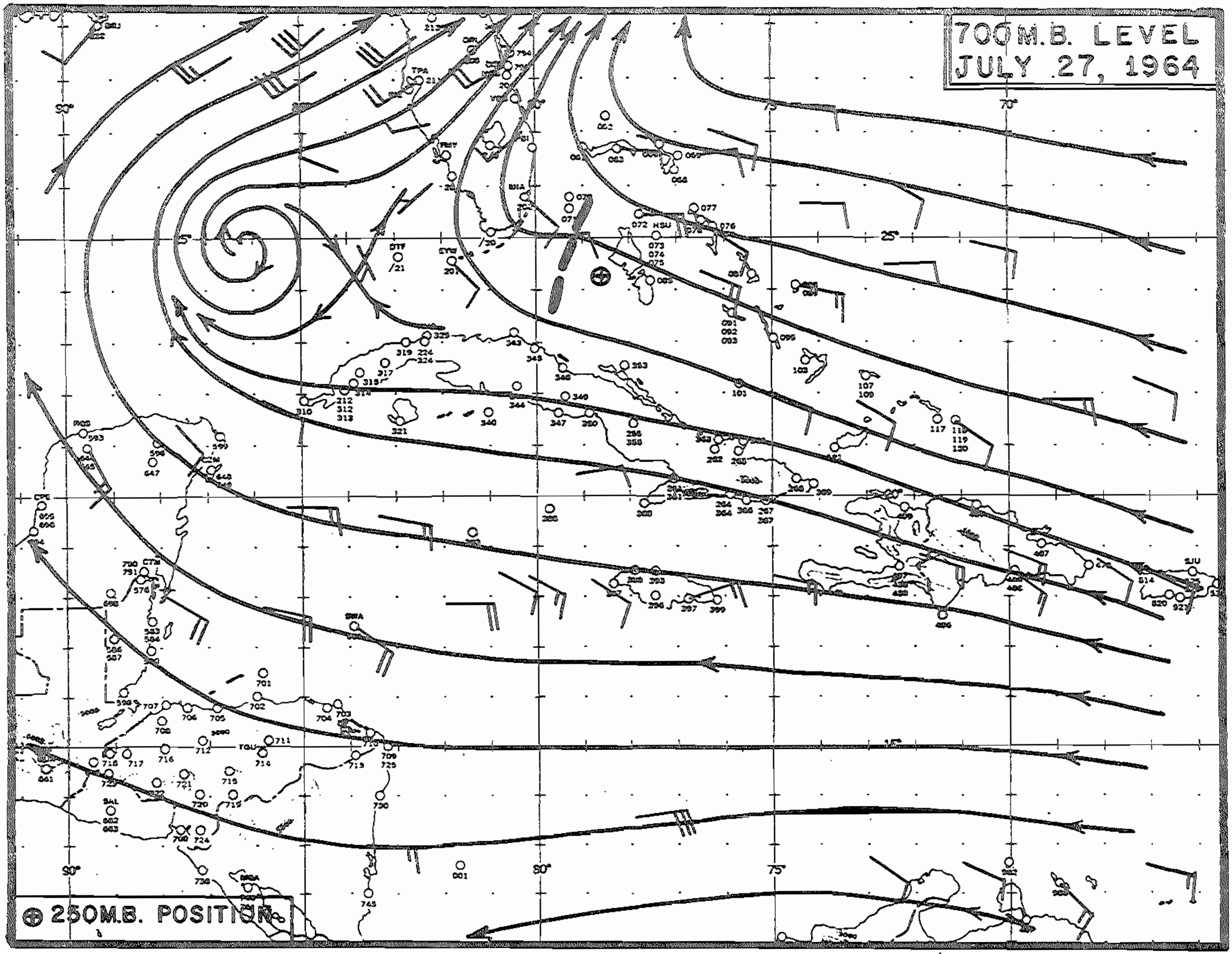

Figure 12. 700 mb Streamline chart showing a weak trough just east of Miami, Florida, which is flection of the upper cold low in Figure 13.

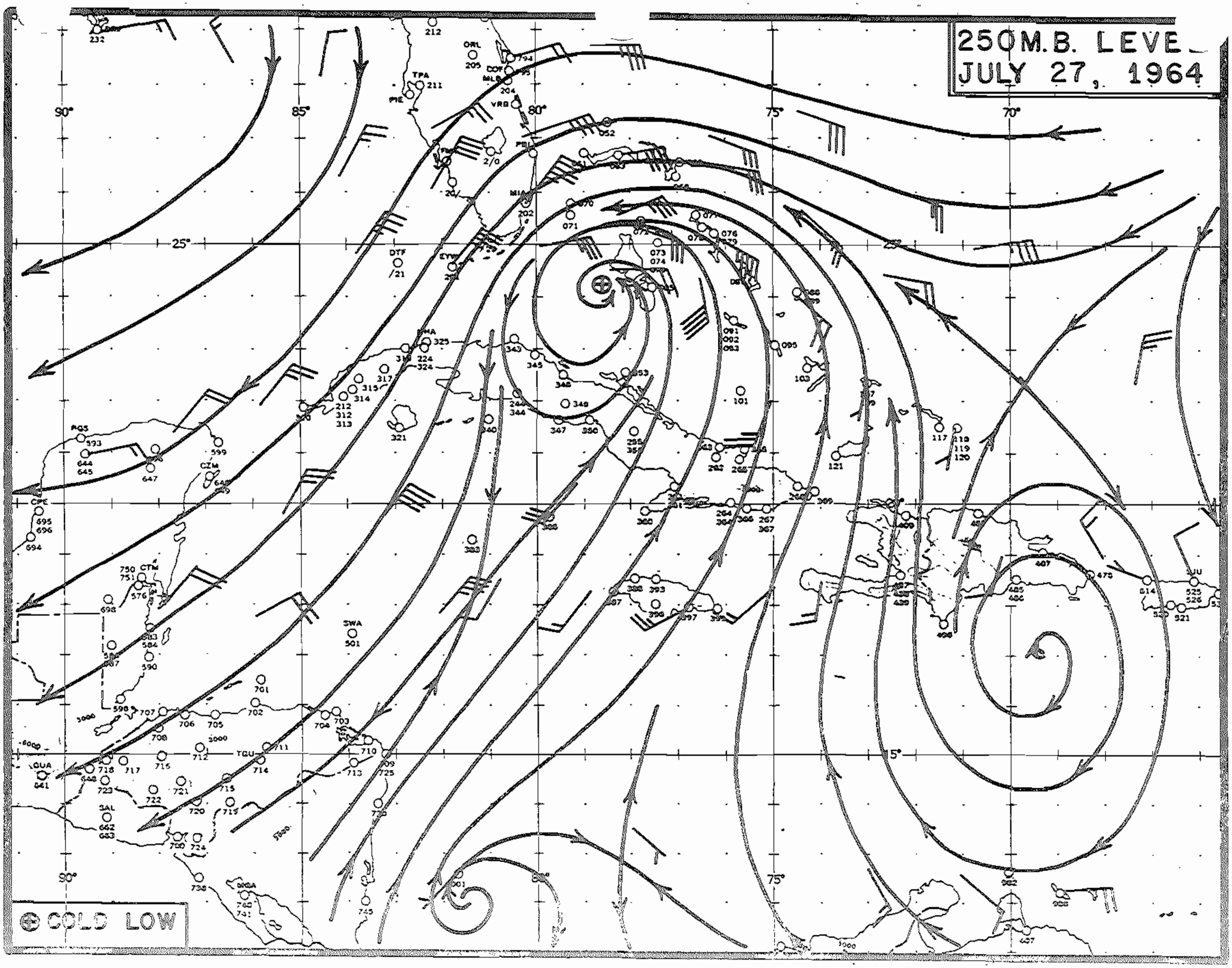

Figure 13. 250 mb Streamline map showing a "dry" cold low. Data on this figure has been composited over 5 map times centered on 12Z.

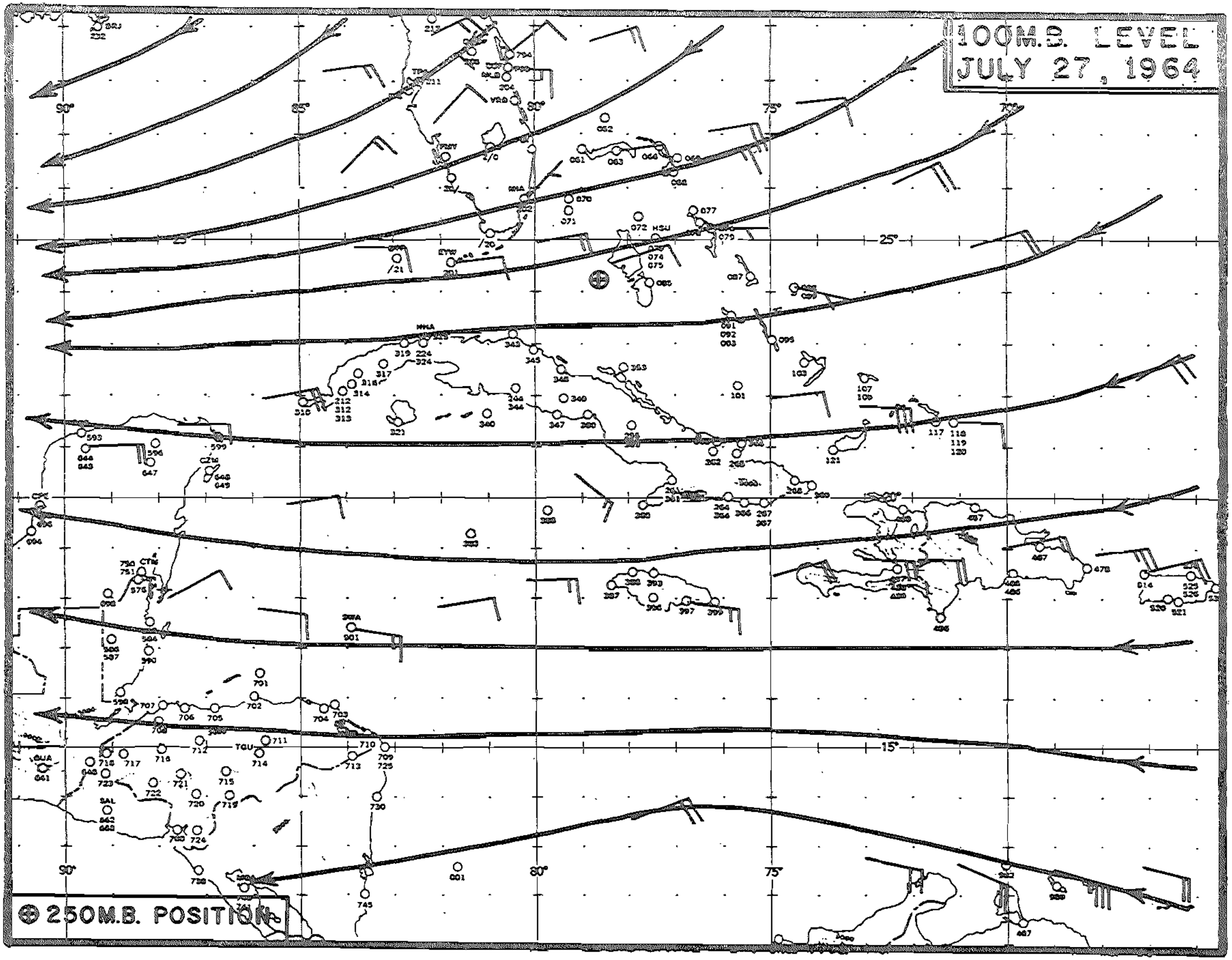

Figure 14. The 100 mb streamline chart for the same low shown in figure 13.

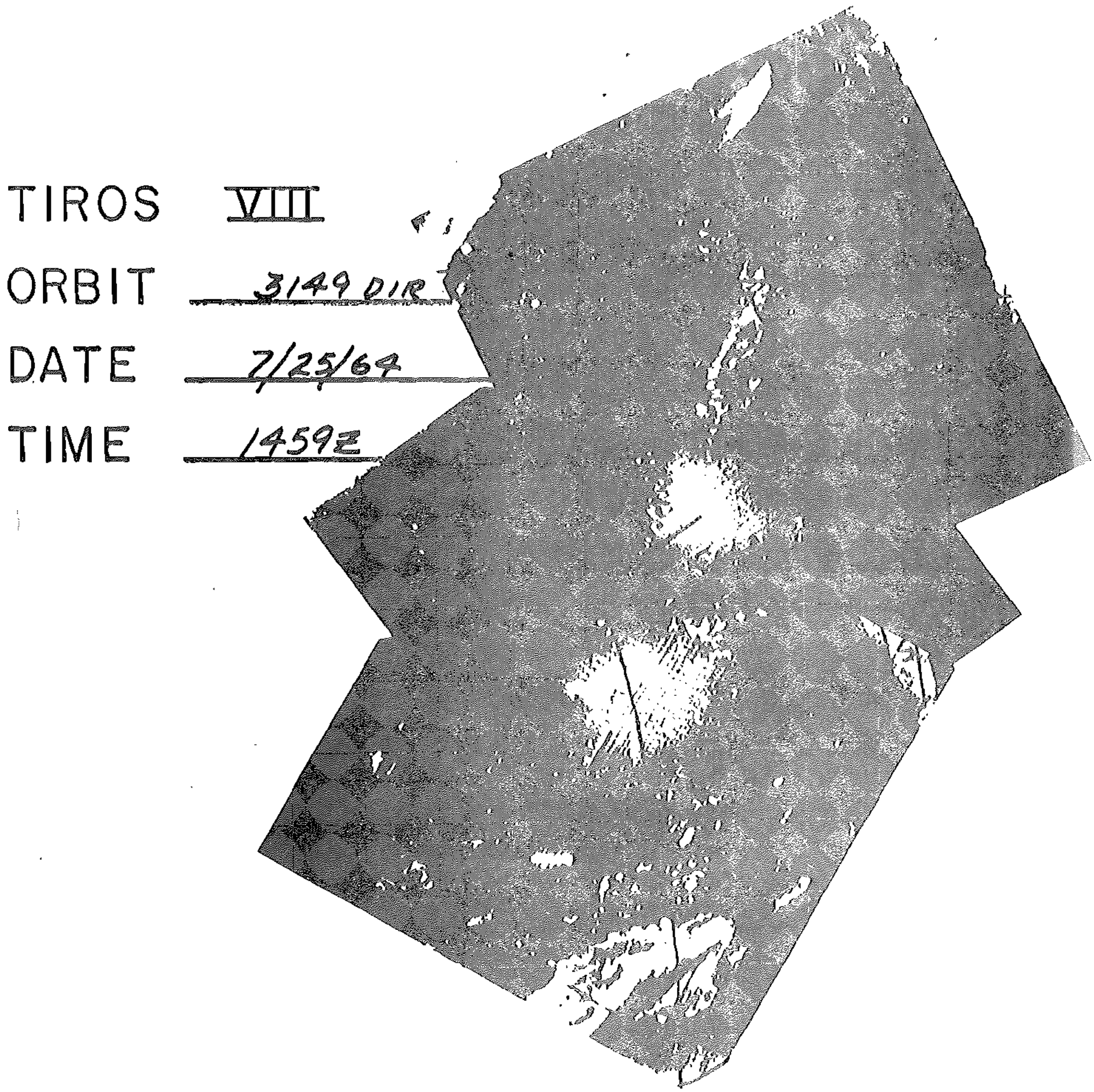

Figure 15. Tiros mosaic on July 25, 1964 showing the weather distribution with the "dry" low of figure 13.

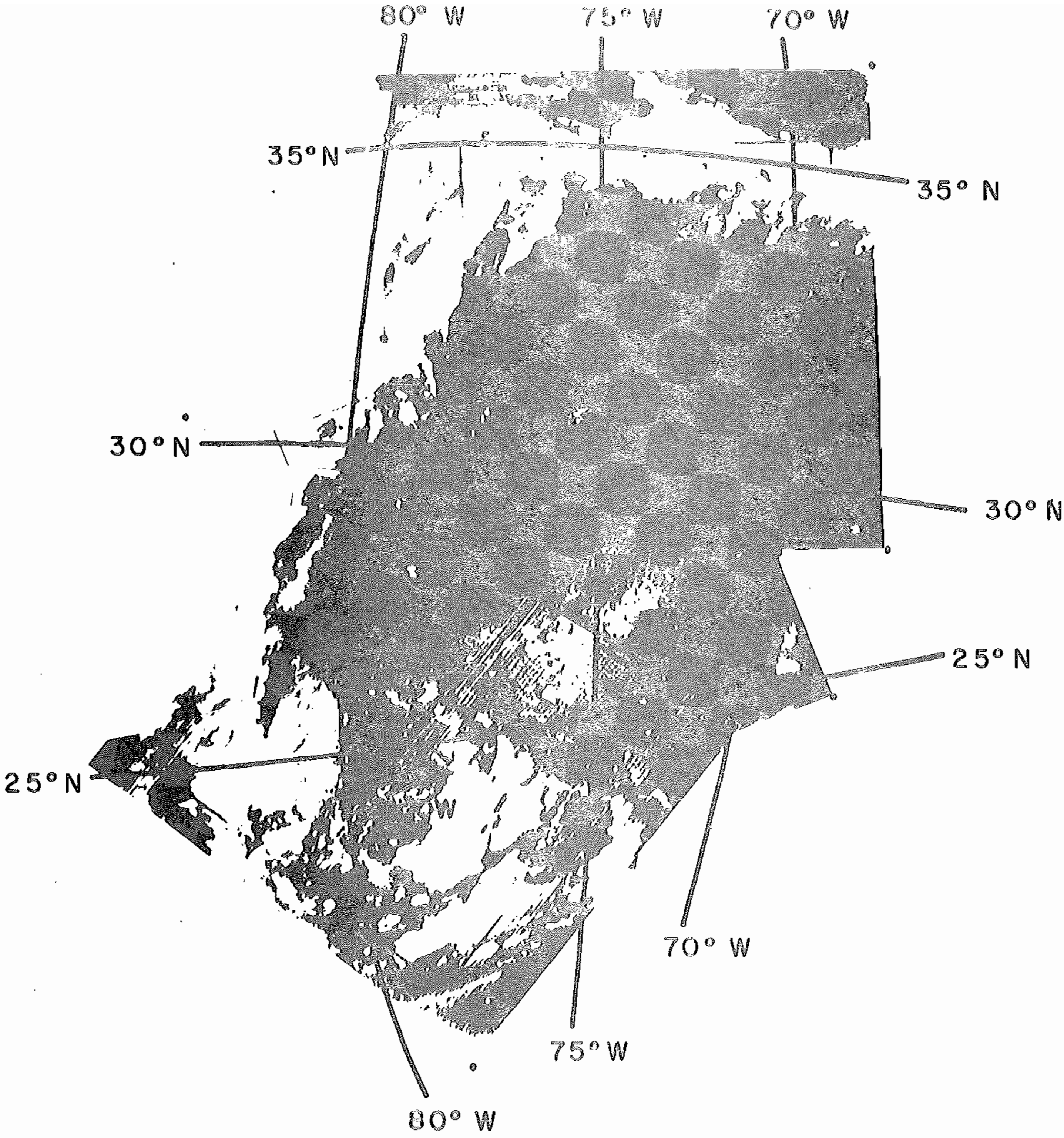

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Figure 16. Tiros mosaic on July 27, 1964 showing the weather distribution with the "dry" low of Figure 13.